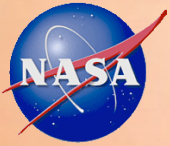


Overview of the NASA Entry, Descent and Landing Systems Analysis Exploration Feed Forward Study

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The Team

EDL-SA

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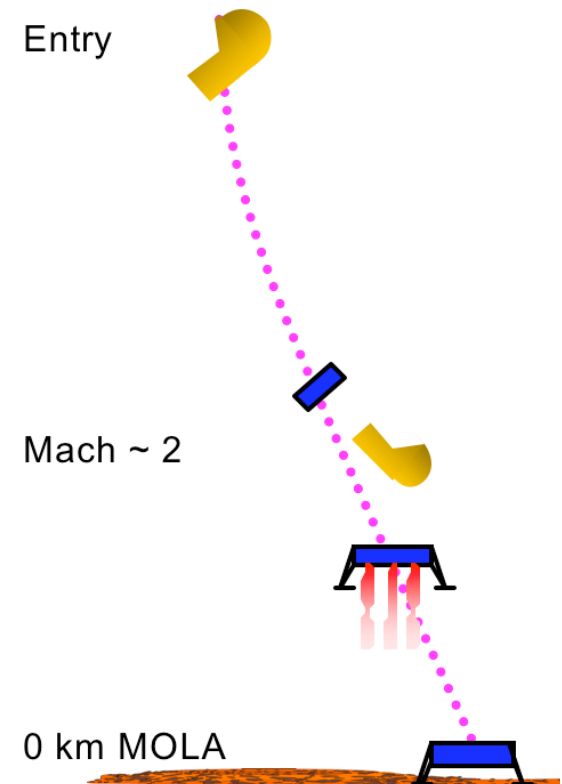
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Mars Design Reference Architecture (DRA5) - 2008

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- **Objective:** To determine minimum required technologies to develop credible AEDL concept that would safely land 40 MT
- **Baseline Mission:** Rigid body (Ellipsled) concept (highest TRL of the candidates) and Supersonic Retropropulsion
 - Eliminated parachutes (too large to be credible)
 - Eliminated inflatables, rigid deployables, etc. (too low TRL, insufficient models)
 - Selected dual-pulse TPS
 - Selected Supersonic Retro Propulsion (note low TRL because of controllability concerns, but deemed best credible solution)
 - Trajectory simulation included low fidelity models
 - Resulted in 110 mt arrival mass





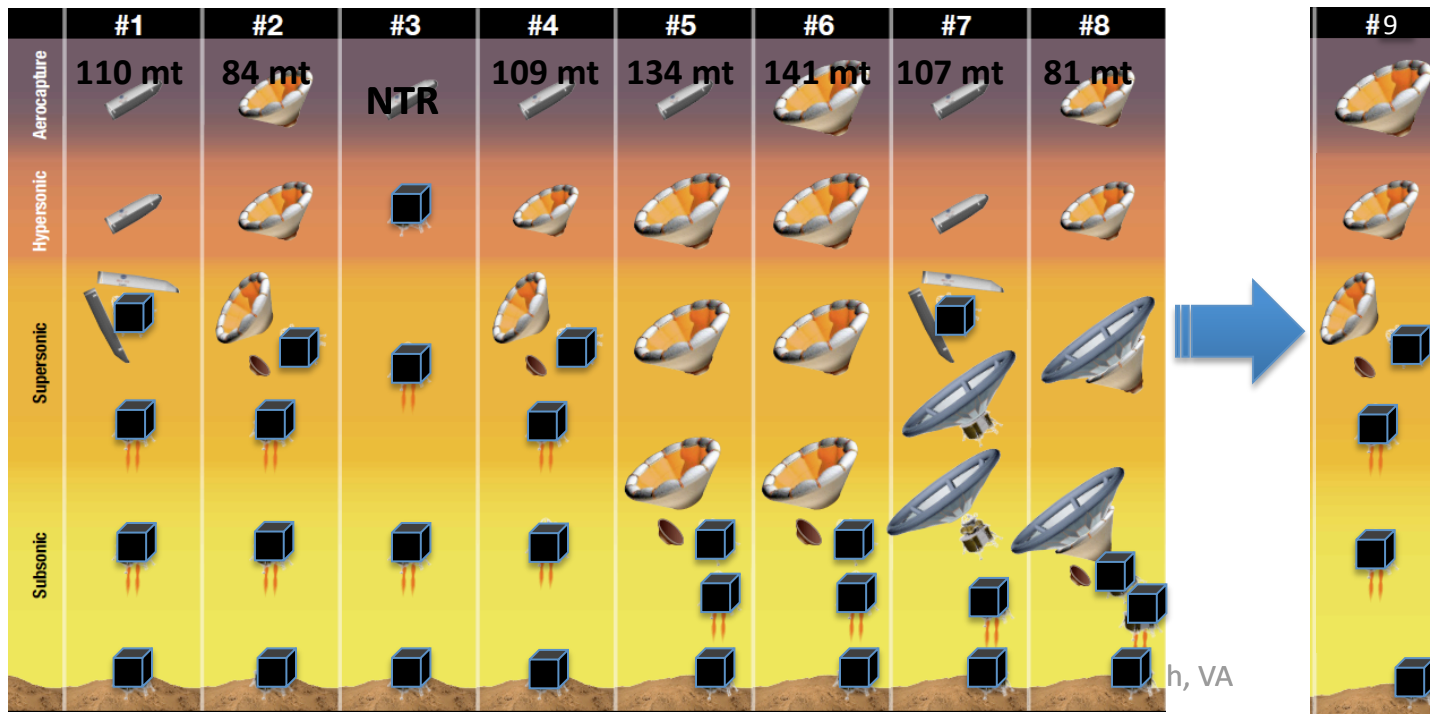
Open the design space to include additional low TRL solutions

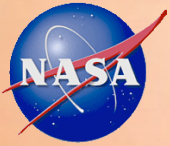
- Performed more detailed analysis of the DRA 5 solution**
- Identified potential alternate technology paths – try to have multiple paths through the technology space**
- Used data from previous studies as a starting point (e.g. used MIAS study (HIAD with ablator TPS) to develop alternative to rigid body)**
- Decided to investigate SIAD with subsonic retropropulsion as alternative to supersonic retropropulsion**
- Recognized that many potential credible solutions were not examined (e.g. rigid deployables)**



EDL-SA: Exploration Class – 2009, cont. EDL-SA

- **EDL-SA Exploration Class Study considered combinations of technologies required to land humans on Mars with**
 - Undefined 40 mt Payload
 - HIAD ablator TPS
 - Bank angle control
- **After Exploration Class External Peer Review**
 - Suggested to consider insulator TPS for Entry and Aerocapture HIADS to compare the mass saving over ablator TPS
 - Suggested that that bank control may not be feasible for large HIADS, so considered CG control





EDL-SA: Exploration Class, cont.

2009

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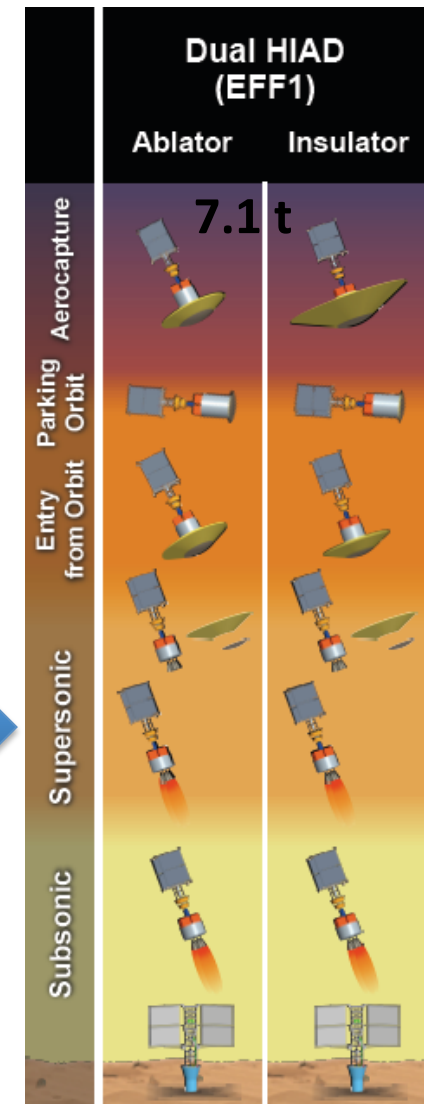
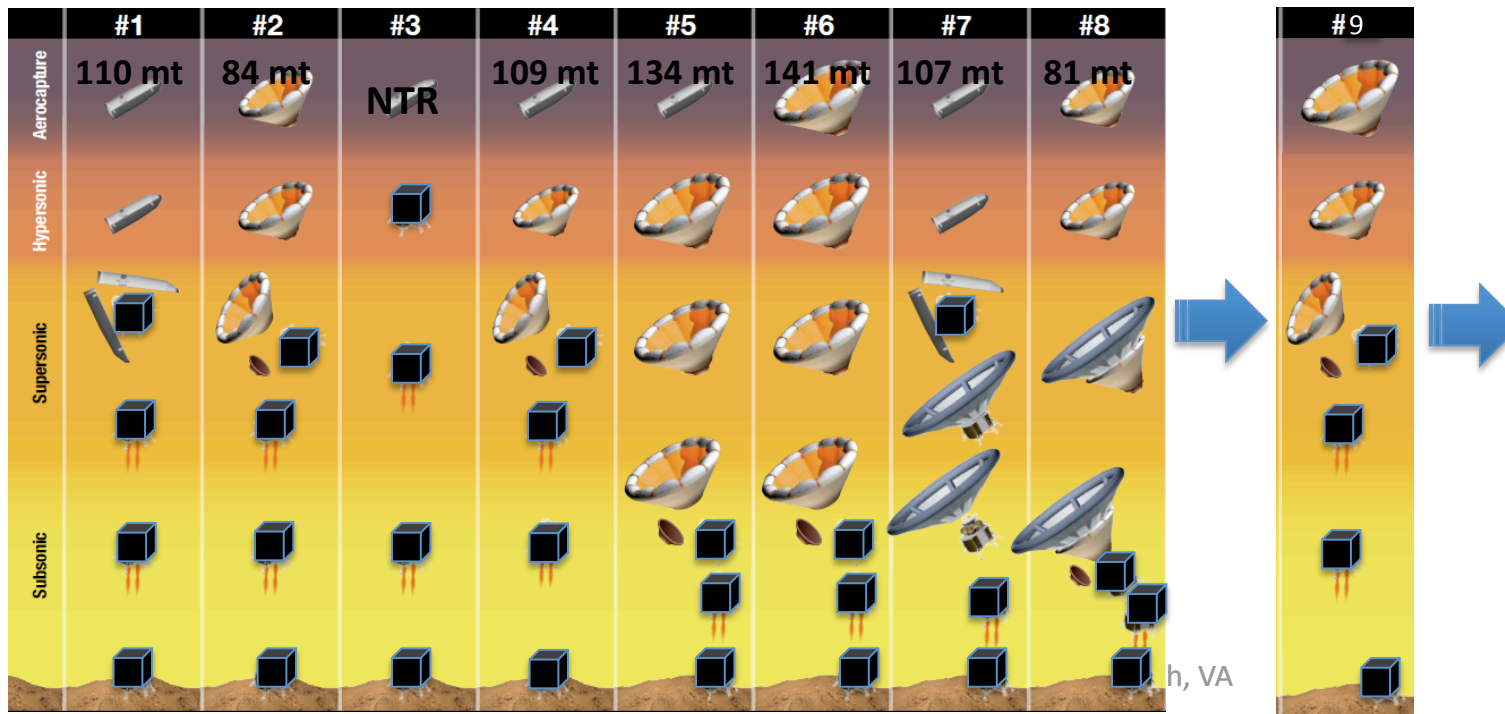
- **Conclusions of Exploration Class Analysis**
 - DRA 5 concept still viable
 - Limited testing of dual pulse TPS showed promising results
 - Replacing SRP with SIAD and subsonic retropropulsion not a good trade
 - No credible alternative to SRP identified
 - HIAD's offered potential for large arrival mass reductions
 - Rigid aeroshells, SRPs and HIADs with ablator TPS were recommended for technology development
- **Transition to Exploration Feed Forward (EFF)**
 - Testing of HIAD insulator TPS material showed promising results
 - Controllability of concept with HIAD remained major concern
 - Updated packaging analysis of DRA 5 aeroshell configuration showed that internal volume was oversized – vehicle could be reduced in size and thus arrival mass should be reduced
 - Recognized that rigid deployables should be added to candidate technology list
 - Decision to split EDL-SA 50/50 with MSL-I limited resources to a single concept (with trades) to carry forward – selected HIAD for aerocapture and EDL



EFF Evolution

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- Extended Arch 9 to assess the next level of design detail using
 - Arrival mass limited to capability of Delta IV-Heavy
 - 2 mt specified Payload (Nuclear Power Plant)
 - Separate HIADS for Aerocapture and Entry
 - HIAD Insulator TPS
 - HIAD controller options - CG, Bank and Combination
 - ALHAT sensor models
 - Supersonic Retro-propulsion (switched from LOX to Hydrazine for Year 2)





EFF Objectives

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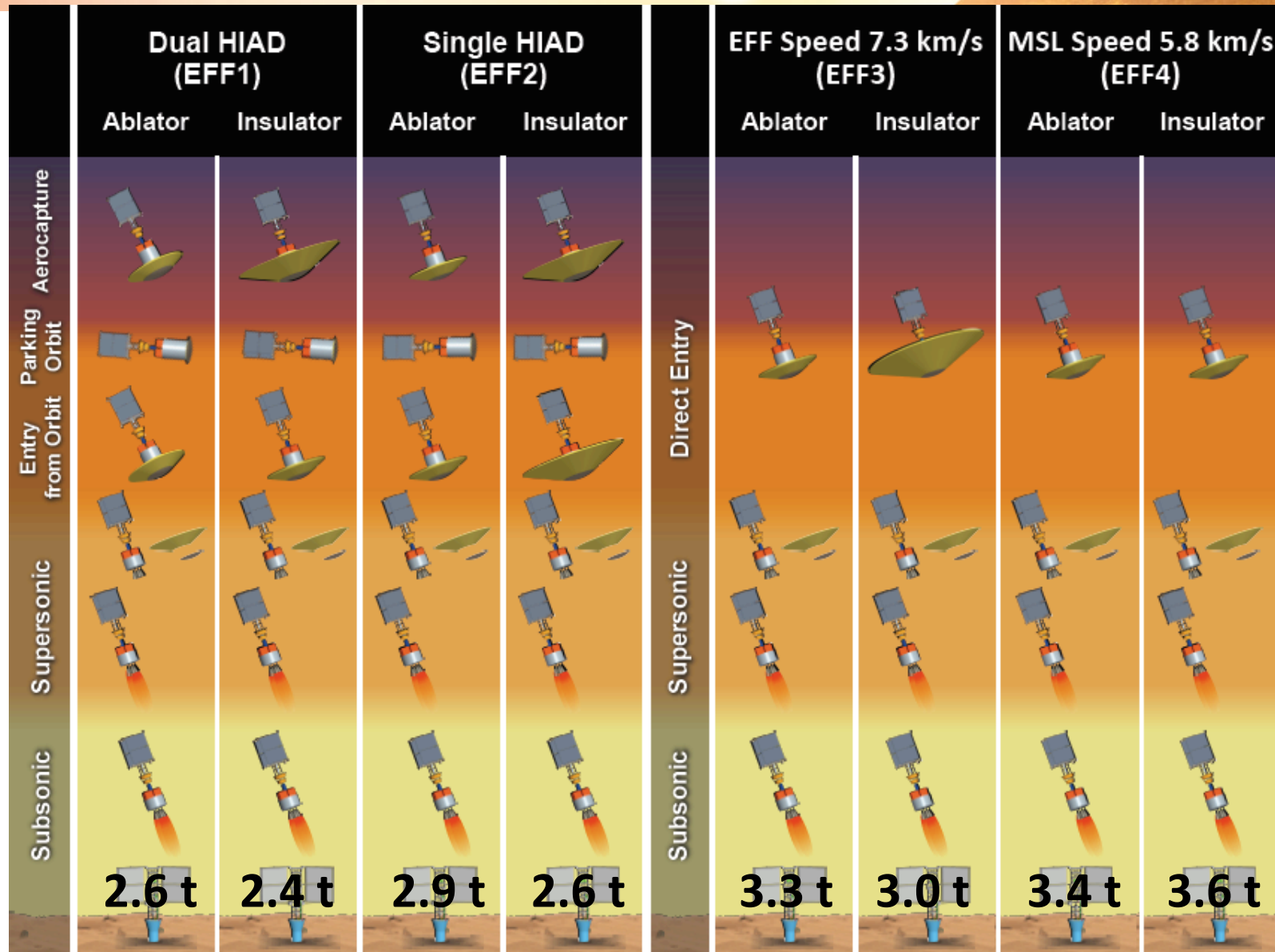
To determine if technologies identified in Exploration Class analysis can be combined in a precursor mission to successfully land a payload of ≥ 2.5 mt

- 1. Determine the maximum payload delivery capability of a Delta IV-H**
- 2. Increase the level of fidelity of all models**
- 3. Determine required performance of supersonic retropropulsion**
- 4. Determine optimal materials, L/D and HIAD size for aerocapture and entry**
- 5. Determine if cg control provides benefits over bank control**
- 6. Determine sensor performance for an ALHAT system at Mars**



Results: Obj. 1 - Optimal Mass

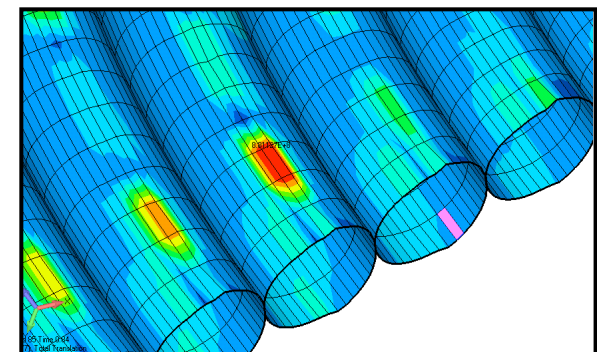
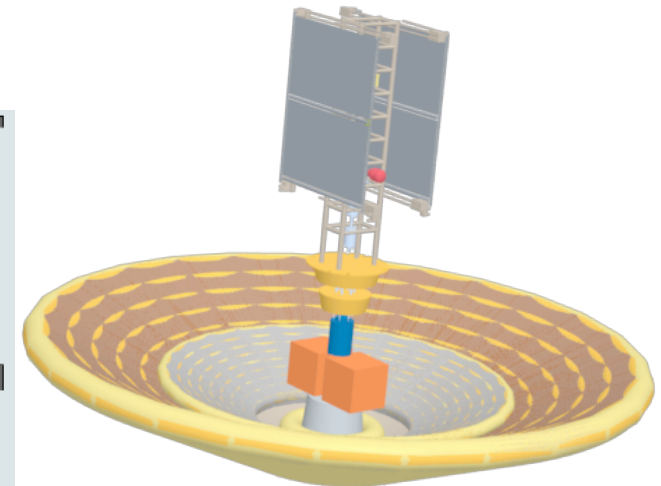
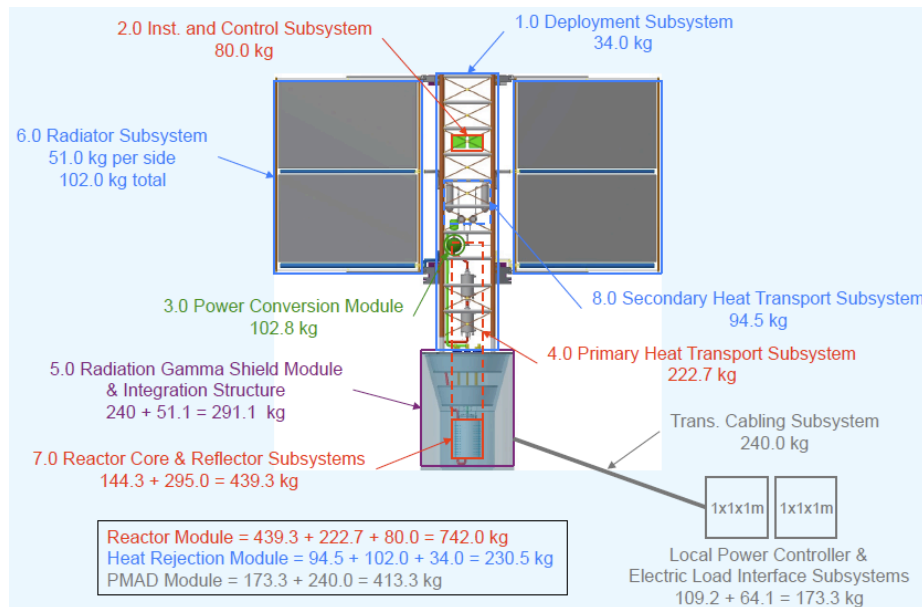
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Results: Obj. 2 - Increase Model Fidelity EDL-SA

2. Perform the next level of detail on **packaging**, **mass properties**, **transitions**, **structures**, **propulsion**, etc





Results: Obj. 3 - 5

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3. Determine the required performance of supersonic retro-propulsion system – **Complete**

RS-72 Pump Fed NTO/MMH throttleable engines, $I_{sp} = 338$ s,

area ratio = 300,

1.4 > Mach at SRP initiation > 1.8

3 km > Altitude at SRP initiation > 8 km

4. Determine optimum material/TPS, L/D, and size of the HIAD for aerocapture and entry – **Complete**

	Units	Dual HIAD		Single HIAD		Direct Entry, 7.2 km/s		Direct Entry, 5.8 km/s	
		Ablator	Insulator	Ablator	Insulator	Ablator	Insulator	Ablator	Insulator
Payload	kg	2627	2371	2881	2589	3294	2953	3442	3584
Diameter	m	8	14	8	14	8	16	8	8

HIAD Controllability examined L/D from 0.1 to 0.25.

5. Determine if active cg control provides benefits over the use of bank only – **Incomplete**



Results: Obj. 6 – ALHAT Performance

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6. Determine the sensor performance ranges for an ALHAT like navigation & sensor system at Mars - **Complete**

TRN

Expected states and ranges

- Altitude: 2 – 7 km
- Velocity: Mach 0.5 – 1.7

Altimeter

- Activated at 6 km

Velocimeter

- Activated at 2 km and 150 m/s

HDA

Current trajectory nominal HDA flight condition

- Altitude = 1 km
- Look angle = -14 deg
- Path angle = 66 deg

Error	Engine Initiation IMU & Star Tracker Updates	Altimeter Update at 6 km	3 TRN Updates b/w 2-7 km	Velocimeter Update at 2 km
Position	4.0 km	2.8 km	125 m	--
Velocity	3.0 m/s	3.0 m/s	--	17 cm/s
Altitude	3.4 km	11 m	--	--



EFF Technology Recommendations

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- **Continue evaluation of ALHAT sensors adapted to Mars**
- **Continue development supersonic retropropulsion**
- **Include rigid body precursor configuration**
- **Continue to mature HIADS**
- **Include rigid deployables in design space**
- **Perform detailed evaluation of transitions**
- **Invest in advancements in flight instrumentation**